Poultry litter valorization to energy

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Abstract

Historically manure has found utilization as fertilizer in agriculture because it contributes to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, phosphorus and potassium. However, the current European Directive 91/676 drastically reduces the application of this material as fertilizer due to its high nitrate content. Therefore, identification of alternative eco-friendly disposal routes with potential financial benefits has become necessary, and the energetic valorization of these biomasses is particularly promising.

Poultry litter represents one of the more challenging bio-fuel feedstocks for energy generation, being easy to handle and showing a composition that potentially assures a high energy content and the production of a byproduct (ash) with good fertilizing properties. In this paper an evaluation of the technical and economic feasibility of the energy conversion technologies usable to recover both the potential energy and fertilizer properties of poultry litter was provided. The focus was posed on the poultry farms of North-East Italy, where more than half of the national poultry production is concentrated.

The preliminary cost analysis suggests that energy production from poultry litter is actually economically viable in the case of large off-site plants only by means of anaerobic digestion, while in the case of small plants operating in situ the gasification process appears the most convenient option.

Keywords: manure, poultry litter, energy recovery.

1 Introduction

Owing to population and income growth, along with changing food preferences, the demand for livestock products is continuously increasing, while globalization is boosting trade in livestock inputs and products. Global production of meat and milk is forecasted to double in 50 years from the beginning of this century,

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reaching 465 million tonnes for the meat and over one thousand million tonnes for milk [1].

The present and future impact of the livestock sector on environmental problems is massive and in this context the management of manure has become one of the most important issues. Historically manure has found utilization as fertilizer in agriculture because it contributes to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, phosphorus and potassium. These disposal methods, however, require proper land application and agronomic rates and soil management to ensure beneficial use and avoid leaching of nitrate and possible transfer of pathogens to the groundwater from fields where high doses of manure have been applied and threatening of soil fertility owing to unbalanced or even noxious nutrients concentrations [2]. As a consequence, land spreading of manure is strictly regulated and in EU the European Directive 91/676 reduces drastically the application of this material as fertilizer.

Therefore, identification of alternative eco-friendly disposal routes with potential financial benefits has become necessary. Schemes providing energy and easy to handle fertilizer as a by-product would be the best alternative route.

To this aim poultry litter represents one of the more challenging bio-fuel feedstocks for energy generation, being easy to handle and showing a composition that potentially assures a high energy content and the production of a byproduct (ash) with good fertilizing properties.

Commercial poultry production is rapidly expanding, growing at 4-5% per year [3, 4], and is expected to continue expansion in the foreseeable future. Nowadays the world magnitude of the poultry industry has reached a total of all types of poultry meat production of about 86 million ton per year [5]. Increases in the demand for poultry products have led to a growth of the dimensions of poultry farms and to a concentration of production, which has caused excessive manure supplies in certain areas.

The poultry industry is very developed in Italy with a poultry meat production of over one million tons per year and an egg production of about 13 billion per year [6]. Moreover, most of the Italian poultry farms are concentrated in a relatively limited part of the national territory. In these areas it is calculated the poultry companies have a mean holding capacity of about 40000 birds, so giving rise to an urgent need for robust and economical high-volume alternative uses for poultry litter.

2 Poultry litter material

Poultry facilities produce litter that is composed primarily of manure, bedding material (wood shavings, saw dust, paper etc.) and feed. Numerous factors determine the quality and composition of the litter, including the bedding material used, the number and type of poultry, the number of flocks per year, and the sources of moisture, other than the overall litter management approach. However, whatever the litter composition, with the exception of ash and water, the other constituents are all potential energetic materials and poultry litter can be directly used for power generation. Moreover, no fuel preparation is required for poultry litter, except possibly some breaking up of clumps.

In the present work, poultry litter coming from the poultry farms of the North-East Italy, where more than half of the national poultry production is concentrated, was considered.

After collection of a representative sample, the poultry litter was dried in the shadow for one week before characterization. The results of the characterization analysis are reported in Table 1.

Table 1: Main characteristics of the considered poultry litter.

Density (kg m^{-3})	
Moisture (mass %)	20.2
Volatile substance (mass % dry basis)	59.5
Fixed carbon (mass % dry basis)	24.9
Ash (mass % dry basis)	15.6
Higher heating value (MJ kg^{-1})	12.72
Element (mass % dry basis)	
Carbon	37.2
Hydrogen	5.52
Oxygen	23.0
Nitrogen	4.4
Sulfur	0.3
Chlorine	0.8

The ash is characterized by an amount of phosphorus as P_2O_5 and potassium as K_2O of 20.2% and 13.8%, respectively.

3 Energy conversion technologies

Three technologies are currently tested as alternatives to land-disposal methods: anaerobic digestion, direct combustion and gasification.

Anaerobic Digestion: it is a biological process where microorganisms convert organic materials to methane, carbon dioxide, and other organic compounds in the absence of oxygen [7]. Anaerobic digesters typically consist of large fermentation tanks with mechanical mixing, heating, and gas collection. The process can be applied at any site that produces organic materials. The efficiency of conversion of manure to methane gas depends on many factors such as quality of manure, retention time in digester, and temperature of the digester [8]. The retention time is strictly dependent on the operating temperature. When the temperature is in the mesophilic range (20-45°C) the typical retention time is 15 to 30 days, however, operating the process with temperature in the thermophilic range (temperature >45°C) the retention time can be shortened to 12 to 14 days.

Thermophilic digestion systems offer higher methane production and better virus and pathogen reduction, but require greater energy input and higher cost of operation compared to mesophilic systems [9].

In evaluating the anaerobic digestion, the amount of volatile matter is of great importance, because typically only the 60% of volatile matter is converted in biogas [9] producing about 0.4 $m^3_{gas}/kg_{volatile\ matter}$. Depending on the waste feedstock and the system design, biogas is typically 55–75% methane. The produced biogas can be used to fuel internal combustion engines that run generators and produce electricity.

When poultry litter is considered, on the basis of its composition an estimated production of $0.22m^3/kg_{litter}$ of biogas is obtained with a typical heating value of 22.4 MJ/m^3. The net electric power generation per MJ of thermal power depends on the method by which the electricity is generated. When a reciprocal engine was considered a 30% efficiency conversion was assumed. With these assumptions the net electric power generation is $0.41kWh/kg_{litter}$

The cost of an anaerobic-digestion system can vary dramatically depending on its size, intended purposes and sophistication. From the quotation of an European supplier for different anaerobic digester sizes (10, 100 and 1000 kWe corresponding to a biogas production of 5.4, 54 and 540 m^3/h) it is obtained a capital cost equal to 11780 € × $(kWe_{installed})^{0.86}$ or 20012 € × $(m^3_{gas\ produced}/h)^{0.86}$, while the running costs per year are estimated from the same supplier to be 2600 € × $(kWe_{installed})^{0.53}$ or 3604 € × $(m^3_{gas\ produced}/h)^{0.53}$.

Direct Combustion: direct combustion is the simplest and most versatile energy conversion technology. Various fuels could be used including different varieties of biomass (e.g., wood, animal manure, agricultural residue, and municipal solid waste). It involves the burning of fuel with excess air, producing hot flue gases that are used to produce steam in the heat exchange sections of boilers. Steam is then used to produce electricity in steam turbine generators.

On the basis of biomass combustion plants running in Italy, the conversion efficiency from thermal to electric power is assumed to be 21% for small plant and 32% for a plant of 10MW or higher. Indeed when poultry litter is considered the net electric generation can be estimated equal to 0.74 kWh/kg_{litter} or 1.13 kWh/kg_{litter} respectively.

The capital costs of direct combustion power plants are very sensitive to plant dimension, varying from 10500 €/kW for a small plant (100 kW) to 2100 €/kW for a 10 MW plant. The running costs are estimated to vary from 1600 €/kW for the former to 146 €/kW for the latter.

It is to consider that when manure is used as fuel an accurate control of emissions is required due to the large amount NO_X generated during the process. Staged combustion is a widely used option for lowering NO_X emissions from a high-nitrogen fuel such as poultry litter. With staged combustion, combustion conditions are somewhat more reducing and less fuel bound nitrogen is converted to NO_X.

Ammonia injection under appropriate conditions also reduces NO_X emissions, and the naturally occurring ammoniacal nitrogen in poultry litter helps keep NO_X emissions low. In some cases, more rigorous NO_X control measures, such as selective catalytic reduction, may be required for poultry litter.

Gasification: in gasification, organic materials are converted into carbon monoxide and hydrogen (i.e., "syngas") that can subsequently be used for the production of a variety of fuels and chemicals. The first step in gasification is pyrolysis where volatile components are vaporized and char (fixed carbon) is produced at temperatures under 600 °C. In the second step, the char and volatile products are combusted with oxygen to form CO and CO_2, generating heat for gasification. In the final step, gasification process takes place where the char reacts with CO_2 and steam to produce CO and H_2. Hydrogen and carbon monoxide are the desired product gases, and they can be directly fired in a reciprocal engine or in a gas turbine for power generation [10].

Gasification of poultry litter at a small scale has successfully been demonstrated and the reported overall energy conversion efficiency is estimated to be 30% [10, 11]. The capital costs for a 100-500 kW plant could be estimated as 1700 €/kW, with running costs of about 180 €/kW. No data were available for larger scale gasifiers.

4 Economic analysis

In Italy the poultry litter production of a mean holding capacity farm and that of a district can be estimated of about 300 t_{litter}/year and 95000 t_{litter}/year, corresponding to a thermal power of about 130 kW and 38 MW respectively.

The revenue from the sale of the net produced electric power depends on the unit price assumed. In Italy the price is actually under definition and is comprised between 0.08-0.15 €/kWh. The evaluation was performed considering a mean price of 0.115 €/kWh. The specific revenue referred to the unit mass of manure R_{sp} (€/kg_{manure}) can be easily calculated by

$$R_{sp}=P_{ee} \times P_{sp}$$

where P_{ee} (€/kWh) is the electric power retail price, and P_{sp} (kWh/kg_{manure}) is the specific electric power generation.

Table 2: Cost analysis for the three considered energy conversion processes.

	Anaerobic digestion		Direct combustion		Gasification
Plant rating kW	50	15000	150	40000	150
Capacity factor (%)	93	98	81	95	80
Capital costs €/kWh	0.973	0.343	7.429	0.599	0.647
Annualized capital costs €/kWh	0.107	0.038	0.817	0.066	0.0712
O & M costs €/kWh	0.084	0.005	1.130	0.055	0.069
Transportation costs €/kWh	0.000	0.031	0.000	0.013	0.000
Total annual costs €/kWh/year	0.191	0.073	1.947	0.134	0.140
Ash value €/kWh	0.000	0.000	0.008	0.005	0.006
Electric power selling price €/kWh	0.115	0.115	0.115	0.115	0.115
Net cost €/kWh	-0.076	0.041	-1.824	-0.014	-0.019

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In an economic assessment it must be considered that both direct combustion and gasification processes produce a by-product, ash, which owing to its content of phosphorus and potassium is a valuable product that can be sold as fertilizer.

The net fertilizer value of poultry litter ash at the energy plant, after accounting for transportation costs, any additional processing costs and marketing costs that may be required, will range from 19 to 60 €/t of ash. In this paper a mean value of 40 €/t is considered [12].

The results relative to the three considered energy conversion processes are reported in table 2. In the table were considered a small plant operating in situ for a mean holding capacity farm and an off-site district plant with a treatment capacity of 95000 of t_{litter}/year. Furthermore a 10 year time frame is considered with a 5% rate of return.

5 Conclusions

The preliminary cost analysis suggests that energy production from poultry litter is actually economically viable only in the case of large off-site plants being the anaerobic digesters the sole that can guarantee a return in a ten year frame.

However, in a full system analysis, the disposal costs of poultry litter when not used to energy production should be taken into account. Other than direct economic factors, a growing number of environmental and social factors have also to be considered, due to their influence and favour on the energy conversion policy. In this context, also options that show negative net costs like small gasification plants operating in situ could be economically viable.

Furthermore, the more and more stringent regulations about land spreading of manures and the growing of the economic value as fertilizer of the residual ash, in the very next future will surely represent an additional incentive for energy production from poultry litter by direct combustion or gasification. Because of valuable nutrient content in the ash, energy recovery (electricity and/or process steam) with ash production could provide a built-in mechanism for economically exporting surplus of phosphorus and associated nutrients out of concentrated poultry areas.

In the complex, energy option is a promising high-volume alternative use for poultry litter leading to an improvement of the environmental sustainability of the poultry industry in its service area.

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